2.0 The Economic Benefits of Sustainable Design

Evidence is growing that sustainable buildings provide financial rewards for building owners, operators, and occupants. Sustainable buildings typically have lower annual costs for energy, water, maintenance/repair, churn (reconfiguring space because of changing needs), and other operating expenses. These reduced costs do not have to come at the expense of higher first costs. Through integrated design and innovative use of sustainable materials and equipment, the first cost of a sustainable building can be the same as, or lower than, that of a traditional building. Some sustainable design features have higher first costs, but the payback period for the incremental investment often is short and the lifecycle cost typically lower than the cost of more traditional buildings.

In addition to direct cost savings, sustainable buildings can provide indirect economic benefits to both the building owner and society. For instance, sustainable building features can promote better health, comfort, well-being, and productivity of building occupants, which can reduce levels of absenteeism and increase productivity. Sustainable building features can offer owners economic benefits from lower risks, longer building lifetimes, improved ability to attract new employees, reduced expenses for dealing with complaints, less time and lower costs for project permitting resulting from community acceptance and support for sustainable projects, and better asset value. Sustainable buildings also offer society as a whole economic benefits such as reduced costs from air pollution damage and lower infrastructure costs, e.g., for avoided landfills, wastewater treatment plants, power plants, and transmission/distribution lines.

Section 2.1 explains how using integrated design and various low-cost sustainable features reduces first costs. Sections 2.2 through 2.5 discuss the other direct economic benefits: annual operating cost savings for energy, water, maintenance and repair, and churn. Sections 2.6 and 2.7 discuss the indirect benefits of sustainable buildings for building owners, and Section 2.8 discusses the indirect benefits of sustainable buildings for society. Case studies and research summaries illustrating various benefits are included in each section.

2.1 Lower (or Equal) First Costs

Sustainable design must begin at the conceptual stage of a project to realize the full benefits. The first step is to form a design team – including the owners, architects, engineers, sustainable design consultants, landscape designers, O&M staff, the general contractor and key subcontractors, cost consultants and value engineers, and occupant representatives. This team needs to work together from the start, seeking an "integrated" design. The team develops innovative solutions that meet energy, environmental, and social goals while keeping costs within budget.

> *"As the green design field matures, it becomes ever more clear that integration is the key to achieving energy and environmental goals especially if cost is a major driver."*
>
> Building Green Inc. (1999)

Using their collective, interdisciplinary analytical capability, the team can incorporate many strategies that, taken alone, would increase first costs. For example, by improving the building envelope, the design team can often eliminate the heating, ventilation, and air conditioning (HVAC) system around the perimeter of the building (and the associated ducting) and also downsize the primary HVAC system. Downsizing the HVAC system and eliminating ducting release money to pay for the envelope improvements. A good example of this phenomenon occurred during the design of the Pennsylvania Department of Environmental Protection's Cambria Office Building. When designers of this building first proposed an upgrade to triple-glazed, double low-e windows, the developer balked at the $15,000 increase in cost. However, the developer was won over when it was demonstrated that this upgrade would allow the perimeter-heating zone to be eliminated for a savings of $15,000, the heat pumps to be downsized for an additional $10,000 savings, and additional space to be gained because of the smaller equipment and ducts for additional rent of $5,000.[8] Also, by eliminating unnecessary features (e.g., expensive finishes), the team can add some more expensive sustainable features that not only meet environmental goals but that also reduce operating costs.

In a sustainable design project, the design team conducts a tradeoff exercise – trading off the cost of optional features against the cost of features that will result in energy, environmental, or social improvements. Focusing on integrated solutions and explicitly evaluating tradeoffs can result in a sustainable facility built for the same (or an even lower) cost than a more traditional building. In most of the government case studies of sustainable buildings included in this document, the first costs were not higher than the original budgeted amount. The following are some design and construction strategies that a team can use to reduce first costs:[9]

- **Optimize site and orientation.** One obvious strategy to reduce first costs is to apply appropriate siting and building orientation techniques to capture solar radiation for lighting and heating in winter and shade the building using vegetation or other site features to reduce the summer cooling load. Fully exploiting natural heating and cooling techniques can lead to smaller HVAC systems and lower first costs.
- **Re-use/renovate older buildings and use recycled materials.** Re-using buildings, as well as using recycled materials and furnishings, saves virgin materials and reduces the energy required to produce new materials. Re-using buildings may also reduce time (and therefore money) associated with site planning and permitting.
- **Reduce project size.** A design that is space-efficient yet adequate to meet the building objectives and requirements generally reduces the total costs, although the cost per unit area may be higher. Fully using indoor floor space and even moving certain required spaces to the exterior of the building can reduce first costs considerably.
- **Eliminate unnecessary finishes and features.** One example of eliminating unnecessary items is choosing to eliminate ornamental wall paneling, doors (when privacy isn't critical), and dropped ceilings. In some cases, removing unnecessary items can create new opportunities for designers. For example, eliminating dropped ceilings might allow deeper daylight penetration and reduce floor-to-floor height (which can reduce overall building dimensions).
- **Avoid structural overdesign and construction waste.** Optimal value engineering and advanced framing techniques reduce material use without adversely affecting structural performance.[10] Designing to minimize construction debris (e.g., using standard-sized or modular materials to avoid cutting pieces and generating less construction waste) also minimizes labor costs for cutting materials and disposing of waste.

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[8] "Pennsylvania Department of Environmental Protection's Cambria Office (DEP Cambria)," a case study in DOE's High Performance Buildings Database at http://www.eere.energy.gov/buildings/highperformance/case_studies/overview.cfm?ProjectID=47.

[9] Many of these concepts were outlined in "Building Green on a Budget." Article found at http://www.betterbricks.com, which cites *Environmental Building News* (May 1999), a newsletter published by Building Green at http://www.buildinggreen.com.

[10] These techniques are explained at http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=70&DocumentID=2021.

- **Fully explore integrated design, including energy system optimization.** As discussed above, integrated design often allows HVAC equipment to be downsized. Models such as DOE-2 allow energy performance of a prospective building to be studied and sizing of mechanical systems to be optimized. Using daylighting and operable windows for natural ventilation can reduce the need for artificial lighting fixtures and mechanical cooling, lowering first costs. Beyond energy-related systems, integrated design can also reduce construction costs and shorten the schedule. For example, by involving the general contractor in early planning sessions, the design team may identify multiple ways to streamline the construction process.

> *"Discovering the DOE-2 model was invaluable. I can't imagine doing this kind of project without it ever again . . . With this technique, we can actually prove to our clients how much money they will be saving."*
>
> Robert Fox, Principal, Fox & Fowle, Architect of Four Times Square, http://www.betterbricks.com

- **Use construction waste management approaches.** In some locations, waste disposal costs are very high because of declining availability of landfill capacity. For instance, in New York City, waste disposal costs about $75.00 per ton.[11] In such situations, using a firm to recycle construction waste can decrease construction costs because waste is recycled at no cost to the general contractor, thereby saving disposal costs.[12] (For an example, see case Study 4-2 in Section 4.)
- **Decrease site infrastructure.** Costs can be reduced if less ground needs to be disturbed and less infrastructure needs to be built. Site infrastructure can be decreased by carefully planning the site, using natural drainage rather than storm sewers, minimizing impervious concrete side-walks, reducing the size of roads and parking lots (e.g., by locating near public transporta-tion), using natural landscaping instead of traditional lawns, and reducing other manmade infrastructure on the site, when possible. For example, land development and infrastructure costs for the environmentally sensitive develop-ment on Dewees Island, off the coast of Charleston, South Carolina, were 60% below average because impervious roadway surfaces and conventional landscaping were not used.

> *"When you don't have all these manicured landscapes and paved roads, you end up with enormous reductions in infrastructure investment."*
>
> John Knott, Chief Executive of Island Preservation Partnership, Dewee Island's developer
> Source: Rocky Mountain Institute website
> http://www.rmi.org/sitepages/pid221.php

In addition to these strategies, certain materials and fixtures that reduce environmental impact have lower first costs than their traditional counterparts (the costs for these products are described in more detail in Appendixes D and E):

- **Concrete with slag content or fly ash.** This product is made with a mix of Portland cement and either iron mill slag (a waste product from blast furnaces that produce iron)[13] or fly ash (a waste product from coal-fired power plants). Vendor quotes gathered during this study indicate that this type of concrete can be slightly less expensive ($0.50 to $1.00 per ton less) than concrete made with 100% Portland cement and is purportedly more durable.

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[11] High Performance Building Guidelines: http://www.ci.nyc.ny.us/html/ddc/html/highperf.html.
[12] See http://www.epa.gov/epaoswer/non-hw/debris/reduce.htm.
[13] The slag is recycled into ground-granulated blast furnace slag cement by grinding the iron blast furnace slag to cement fineness.

- **Carpet with recycled content.** A range of environmentally preferable carpet products is currently available on the market, including refurbished used carpet and new carpet made from various combinations of old carpet, carpet scraps, carpet backing, auto parts, soda bottles, and flooring materials. The quotes gathered for this study indicate that such sustainable carpet options can cost as much as $15 less per yard than traditional carpet (although some price quotes indicated the recycled carpet was more expensive).

- **Low-emitting paint and recycled paint.** Low-emitting paint has very low or no emissions of volatile organic compounds (VOCs) when it is applied. For building occupants, the paint significantly reduces negative reactions that normal latex paint often causes and allows buildings to be occupied during or shortly after the paint is applied. Price quotes gathered for this study vary, but some indicate that low-emitting paint can cost $3 per gallon less than normal paint and can cover more surface area per gallon.[14]

  Recycled paint is "left-over" paint collected from construction sites or the paint manufacturing process. That paint is then sorted by type, color, and finish and reprocessed for resale. Price quotes collected for this study indicate that recycled paint can sometimes be $15 per gallon less expensive than comparable "virgin" contractor-grade latex paint.

- **Certified wood products.** Such products comply with Forest Stewardship Council Guidelines, indicating that wood producers have applied all regional laws and international treaties, respect long-term tenure, and use rights on the land from which the wood is harvested. Price quotes indicate that some certified wood doors are $150 less expensive than traditional doors (although some are more expensive).

- **No-water urinals.** Urinals that use no flushing water often cost less to install than traditional, water-using urinals because of the reduced need for pipes (no intake water is required). Price quotes indicate that some brands of no-water urinals cost over $280 less (per urinal, installed) than their water-using counterparts. (Also, see Section 2.3 for annual water cost savings).

Implementing all of the sustainable features discussed above (concrete with slag content, recycled carpet, low-emitting paint, certified wood doors, and no-water urinals) reduced the first costs of the prototype building that was examined in this study (see Section 1) by up to $2.60/ft^2 and the total first cost of the building construction by as much as $51,000, lowering the total building cost by about 2%.

Case Study 2-1 shows how reducing project size and using integrated design principles can significantly reduce first costs. Focusing only on strategies that keep first costs low may not be in the best long-term interest of the building owner. Some features that increase first costs can significantly reduce lifecycle costs. Some of these lifecycle cost reduction strategies are discussed in Sections 2.2 through 2.5.

[14] Various brands of low-emitting paint were compared with their traditional counterparts. To provide reasonable points of comparison with the low-emitting paint, costs for both normal contractor-grade and high-end products were included. The cost of the low-emitting paint varied depending on location of the purchase, volume of the paint purchased, and the ability of the local distributor to offer special rates.

Case Study 2-1: Zion National Park Visitors Center Reduces Energy Consumption While Cutting Construction Costs

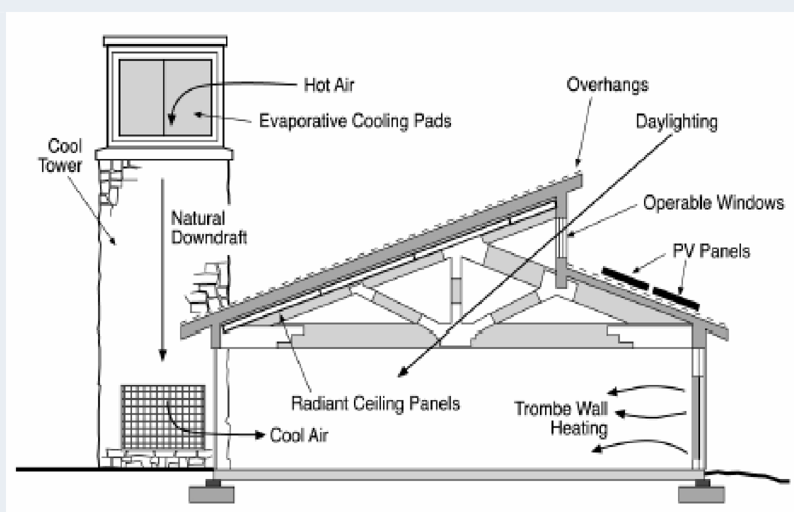
This case study shows that an integrated design team can apply fairly simple natural principles in innovative ways to significantly reduce energy consumption. A high-performance building does not necessarily cost more to build than a more typical building. One way to reduce first costs is to consider making changes to the general building program (overall concept, scope, and requirements). In this case study, exhibit space was moved outdoors.

Project Description: The Zion National Park Visitors Center in Springdale, Utah, is a small building (7,600 ft^2) designed to allow park visitors access to park information, interpretation, and trip-planning assistance. The facility provides both indoor and outdoor exhibit spaces.

Approach to Sustainable Design: The design team used a "whole building design" process from the onset of the conceptual design through completion of the commissioning process. Instead of using a two-staged design approach in which the building design is developed first, followed by the engineering design of the heating, lighting, and other mechanical systems, this design team viewed the building project as a single system. The team worked to ensure that the building envelope and systems complemented each other. Extensive whole-building energy and lighting computer simulations were conducted throughout the design process.

Sustainable Features: The building includes features such as natural ventilation and evaporative cooling, passive solar heating, daylighting and sunshading, computerized building controls, and an uninterruptible power supply integrated with a photovoltaic system. The natural ventilation and cooling are facilitated by a cooltower, a passive solar approach that has been used for hundreds of years. Water is pumped onto a honeycomb media at the top of the tower, cooling the air by evaporation. This cool air descends naturally (without fans) through the tower and into the building. Strategically placed windows help evacuate hot air and circulate the air. The building's envelope and general form, including overhangs, clerestories, roofline, and massive building materials, help reduce energy consumption.

After the building envelope was designed, the small amount of remaining heating required was met with electrically powered radiant heating panels, which were estimated to be the most cost-effective solution and eliminated the need for a central heating system that would have required a hot-air furnace or boiler and associated ductwork or piping. Daylighting (provided by clerestory windows and windows six feet above the floor) meets the primary lighting needs, but a high-efficiency electric lighting system and related controls were designed to complement the daylighting design. The uninterruptible power supply system was included in the original

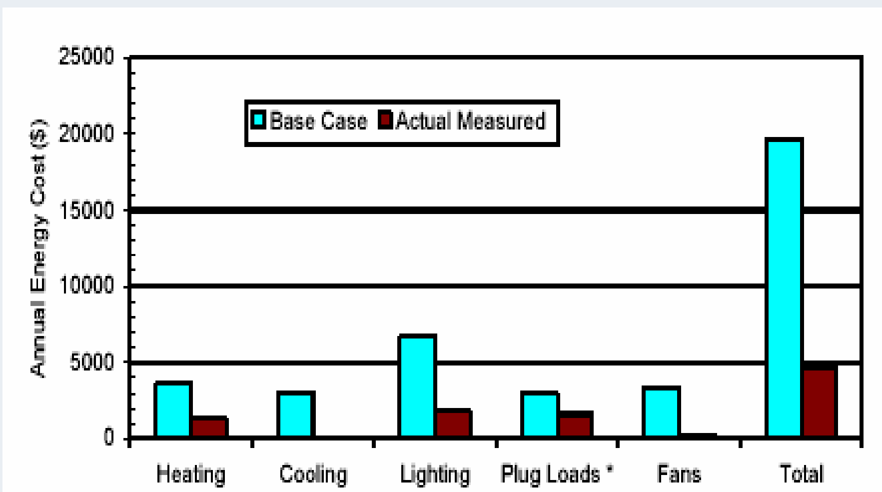


Energy-Related Features of the Visitors Center

plan for the building's electrical system because of poor power reliability at the site. The design team specified an inverter that could handle input from a solar-electric system, so the building was ready to be outfitted with a solar-electric system. Later in the design process when additional funding was available, a 7.2-kW solar-electric system was installed. The figure (previous page) shows the design's main features.

Financial Considerations: The project construction cost was estimated to be about 30% less than that of a conventional visitors center. This lower cost is primarily the result of a decision made early in the design process to move many of the exhibit spaces outdoors under permanent shade structures to decrease building size. To ensure that the outdoor exhibits were noticed, the designers separated the visitors center from the restrooms (comfort station), so visitors would walk through the outdoor exhibit space.

In addition, the floor space required for the building support functions (i.e., the mechanical room) was smaller than in a conventional visitors center because eliminating ducts, large blowers, chillers, and boilers reduced the size of the mechanical room. Eliminating the need for fuel storage (by using electrically powered radiant heat) also reduced infrastructure costs. The figure below summarizes annual energy costs based on measured performance (NREL monitored the performance). The building was designed to use most of its power during offpeak periods, when power is cheaper. The building's operating costs is only $0.45/ft^2 ($4.84/m^2) to operate. The NREL team found that the Zion Visitors Center Complex is using 70% less energy compared with facilities built to the applicable Federal codes.[15] This energy use is equivalent to a total annual savings of about 250,000 kilowatt-hours (kWh) (870 million Btu).



Measured Energy Cost Performance of the Visitors Center (Torcellini et al. 2002)

Sources: Torcellini et al. (2002); DOE's High Performance Buildings Database at URL: http://www.eren.doe.gov/buildings/highperformance/case_studies/overview; and personal communication with P. Torcellini, NREL, Golden, Colorado.

[15] The 70% reduction was calculated from a theoretical base-case building, which was modeled to provide a starting point for the analysis and as a metric for evaluating the project's energy-savings success. The base-case model has the same footprint area as the as-built building. The base-case building is solar neutral (equal glazing areas on all orientations) and meets the minimum requirements of the Federal Energy Code (10 CFR 34). Electric lights provided all lighting for the base-case building and were set to retail and exhibit lighting levels. More detail on the base-case versus as-built building is available from Torcellini et al. (2002) on DOE's Energy High Performance Buildings website: http://www.eren.doe.gov/buildings/highperformance/case_studies/overview.

2.2 Annual Energy Cost Savings

A wide range of building design approaches and commercially available technologies can help effectively minimize a building's energy costs. As Section 2.1 discussed, an important concept in energy-efficient design is integrating the building's architectural and mechanical features to minimize energy use and reduce cost while maintaining comfort. This integration is best done during the very early stages, when the most cost-effective holistic system can be designed. Although some energy-efficiency strategies result in slightly higher first costs, the resulting annual cost savings result in lower lifecycle costs.

To illustrate this concept, PNNL and NREL analyzed the energy costs that could be saved by using an integrated design approach to alter architectural elements and mechanical systems in the prototype two-story building of 20,000 ft^2, hypothetically located in Baltimore, Maryland. The base-case building, to which the sustainable building was compared, is assumed to meet the levels of energy efficiency in the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 90.1-1999 standard (this is also the baseline for LEED energy-efficiency credits). The total construction cost of this base-case building was estimated at $2.4 million. Using two energy simulation models (Energy-10 and DOE-2.1e) and standard costing approaches (see Appendix B for details), the analysis team calculated the incremental first cost[16] and annual energy cost savings, as well as lifecycle costs[17] and payback periods, for a combination of energy-saving features, optimized for lowest energy use and lifecycle cost (see Figure 2-1).

The results indicate that annual energy costs could be reduced 37% below the base case[18] by incorporating various energy-saving features, at a total first cost increase of about $38,000 (adding 1.6% to total first costs). The overall simple payback[19] for the changes was estimated to be 8.7 years, and the sustainable building had a net lifecycle savings of over $23,000 during the assumed 25-year lifetime. The savings-to-investment ratio[20] was estimated to be 1.5. Table 2-1 shows the breakout of the savings. For example, the added skylights, combined with lower overall lighting intensity and lighting controls, decreased the lighting energy consumption by about 48% and saved over $2900 in annual energy costs. Table 2-2 compares some additional values between the base case and the sustainable option (prototype building).

The energy-efficiency analysis of the prototype building indicates that significant amounts of energy can be reduced within an acceptable payback period and that energy-efficient buildings can have lower lifecycle costs than their traditional counterparts. The cost analysis of the Johnson City Customer Service Center being designed by the Tennessee Valley Authority (Appendix C) provides another example.

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[16] Incremental first cost is the additional capital expenditure needed to include the sustainable design feature (a negative incremental first cost indicates a capital cost savings).

[17] Lifecycle cost represents the first cost plus the replacement costs (discounted to present value) that occur over the lifetime of the equipment, minus the discounted present value of the stream of cost savings.

[18] This value excludes "plugloads," the energy use by equipment and machines in buildings.

[19] Simple payback equals the incremental first cost divided by the annual cost savings.

[20] The savings-to-investment ratio is similar to a benefit-cost ratio and equals the discounted present value of the stream of annual cost savings over the lifetime of the investment, divided by the incremental first cost plus the discounted value of future replacement costs. A savings-to-investment ratio greater than 1.0 indicates that the present value of the savings exceed the present value of any additional capital outlays.

Energy-Efficiency Measures Examined in the Prototype Building Analysis

Lighting Measures

- **Increased daylighting.** Skylights were added, increasing daylight to the top floor.
- **Reduced lighting intensity.** Lighting power densities recommended by the Illuminating Engineering Society of North America and ASHRAE, as a proposed addenda to the 90.1 standard, were adopted. The lighting level was reduced from 40 to 35 footcandles in the office area, with some increase in task lighting.
- **Perimeter daylighting controls with dimmers.** Daylight sensors (six per floor) control stepped ballast controls so that electric lighting is dimmed when sufficient daylight exists. In the base case, no dimming of electric lighting occurs.

Envelope Measures

- **Window distribution.** The square footage of the windows was redistributed to optimize solar gain with heating and cooling costs. The optimized window-to-wall ratio is 15% window for the north wall, 10% window for the east and west walls, and 30% window for the south wall. The base-case ratio is 20% for all walls.
- **Additional wall insulation.** On the outside face of the exterior wall framing, R-10 rigid insulation was added compared with only R-13 batt insulation in the base-case walls. The resulting insulation in the sustainable building was R-23.
- **Additional roof insulation.** The R-15 rigid insulation was increased to R-20.
- **White roof.** A white roof finish material with low solar radiation absorptance of 0.30 was used compared with the base case's absorptance of 0.70.
- **Highly energy-efficient windows.** The sustainable option balances window performance with the low lighting levels and the use of daylighting controls. The result is a cost-optimized window with a U-factor of 0.31 and a shading coefficient of 0.39.

Mechanical Systems

- **High-efficiency air conditioner.** The air conditioning unit has an energy-efficiency ratio of 13 compared with 10 for the base case.
- **High-efficiency water heater.** A 90% thermal efficiency condensing water heater was used compared with a commercial gas water heater with 80% thermal efficiency for the base case.
- **Low-pressure ducts.** The fan external static pressure was reduced from 1.0 inch water column to 0.5 inch water column by enlarging the duct sizes.
- **Economizers.** An integrated economizer, including an outside air enthalpy sensor with a high-limit enthalpy setpoint, was used; the setpoint was set at 25 Btu/lb in conjunction with a dry bulb temperature high limit of 74°F.

Figure 2-1. Energy-Efficiency Measures Examined in the Prototype Building Analysis

Table 2-1. Prototype Building Analysis: Energy-Efficiency Features Reduce Annual Energy Costs by 37%

	Base-Case Building Annual Energy Cost	Sustainable Building Annual Energy Cost	Percent Reduction
Lighting	$6,100	$3,190	47.7
Cooling	$1,800	$1,310	27.1
Heating	$1,800	$1,280	28.9
Other	$2,130	$1,700	20.1
Total	$11,800	$7,490	36.7
* Values are rounded to three significant digits.			

Table 2-2. Prototype Building Analysis: Costs and Benefits of Energy-Efficiency Measures*

	Base Case	Sustainable Building
Total first cost of building (million $)	$2,400	$2,438
Annual energy cost		
Dollar amount	$11,800	$7,490
Percent change from base case	NA**	-36.7
Economic metrics		
Simple payback period (yr)	NA	8.65
Lifecycle cost (thousand $)	$2,590	$2,568
Percent change in lifecycle cost from base case	NA	-0.9
Savings-to-investment ratio	NA	1.47
Energy use		
Million Btu	730	477
Percent change from base case	NA	-34.6

* Values have been rounded to three significant figures.
** NA = not applicable.

In addition to integrating architectural elements and high-efficiency mechanical systems to reduce annual energy use, various measures can be taken to lower the energy use by equipment and machines in buildings (plug loads). For instance, the marketplace now offers Energy Star™ computers, office machines, and appliances,[21] and the Federal government mandates the purchase of these energy-efficient machines for its facilities. In addition, innovative entrepreneurs have begun introducing new products that help reduce unnecessary energy consumption and have short paybacks. For example, one commercially available device reduces the electricity consumed by vending machines by up to 46% with a payback period of 1 to 2 years, while maintaining the proper temperature of the beverages or other products.[22]

Another important aspect of achieving energy efficiency in a new building is "commissioning," which refers to the validation and checking process undertaken before the building is occupied to ensure that the performance of the building and its systems satisfies both the design intent and occupants' needs. In sustainable building design and construction, the need to commission is greater than ever because of the interactive synergies between the various mechanical and electrical systems and the building's architectural features (U.S. General Services Administration [GSA] and U.S. Department of Energy [DOE] 1998). Data substantiating the benefits of commissioning new buildings are difficult to obtain because benefits must be estimated against a modeled baseline or compared with a similar building. However, a database of 175 commissioning case studies by Portland Energy Conservation, Inc. (PECI) (1997) of various types of commercial buildings ranging from new to 74 years old consistently demonstrated significant energy savings and improvements in thermal comfort, indoor air quality, and overall O&M. Table 2-3 shows the estimated costs of commissioning a new building.

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[21] This study did not include a thorough analysis of reducing plug loads. The LEED system does not apply points to this category. In some cases, energy-efficiency improvements depend on the behavior of building occupants and therefore cannot be guaranteed. The plug load in the prototype building represents about 25% of the energy consumption.
[22] www.bayviewtech.com.

Table 2-3. Costs of Commissioning for New Construction (PECI 1997)

Scope of Commissioning	Cost
Whole building	0.5-1.5% of total construction cost
HVAC and automated controls systems only	1.5-2.5% of mechanical system cost
Electrical systems commissioning	1.0-1.5% of electrical system cost

The first cost for the HVAC and control system in the prototype building analyzed in this study was about $212,000 (out of a total cost of $2.4 million), and the annual energy costs of the base case were modeled to be $11,800. Using the values in Table 2-3, commissioning the HVAC and control system would cost from $3180 to $5300 (1.5% to 2.5% of HVAC and control system costs). Assuming that the commissioning would reduce energy costs by 10%,[23] the annual costs savings would be about $1310, resulting in payback period from 2.4 to 4.0 years.

In addition to commissioning the building before it is occupied, a building designed for sustainability must also be operated and maintained with the same goal in mind. O&M activities include 1) controlling and optimizing procedures and systems and 2) performing routine, preventive, scheduled, and unscheduled actions to prevent equipment failure or decline and to meet efficiency, reliability, and safety goals.

In a sustainable design environment, O&M requirements must be identified and addressed in a building's planning stage to ensure that control systems are installed, that the building and equipment are designed for ease of O&M, and that sufficient O&M resources (staff, materials, replacement parts, etc.) are included in the annual budgets. Studies of commercial buildings estimate potential O&M-related energy savings to be from 5% to 30% (Hunt and Sullivan 2002). Buildings designed for sustainability need to focus on maximizing savings through a proactive O&M program that focuses on operational efficiency.

One component of such a program is the periodic recommissioning of equipment, which involves rechecking and recalibrating the original equipment. Examples of typical O&M and recommissioning activities include calibrating sensors, checking/resetting temperature setpoints, maintaining proper building operating schedules, balancing/rebalancing the HVAC systems, changing filters, metering/submetering energy with analysis and followup action as appropriate, and training and certifying operators for building mechanical/electrical equipment and systems. PECI (1997) estimates $0.17/ft^2$ as the average cost to recommission existing buildings. Applying this cost rate to the Federal building inventory and assuming a 10% resulting reduction in energy use yield a simple payback for recommissioning of 1.4 years for energy savings alone (Hunt and Sullivan 2002).

Case Study 2-2 demonstrates how significant energy was saved using many of the techniques just described, including energy-efficient mechanical equipment and commissioning.

[23] This is within the range of 5% to 30% estimated for savings associated with sound O&M. To estimate the cost reduction of $1310, the energy cost was assumed to have been 10% higher had no commissioning occurred, i.e., it would have been $11,800/.9 or about $13,100. A 10% savings, based on an original annual energy cost of about $13,100, is $1310.

Case Study 2-2: Facility at Sandia National Laboratories Reduces Energy Costs

This case demonstrates that a significant amount of energy can be saved by analyzing energy consumption using models and choosing technologies with favorable lifecycle costs.

Project Description: The 151,000-ft^2 Process and Environmental Technology Laboratory in Albuquerque, New Mexico, houses 180 people in a central core of labs with offices on the perimeter. By carefully considering cooling, heating, and process/electrical loads and revising the design, the team increased energy efficiency by over 20% between the preliminary and final designs.

Approach to Sustainable Design: The design for this building focused only on the energy aspects of sustainability. The efforts began when energy modeling during the first phase of the design process showed consumption that exceeded by 20% the average annual energy use of Sandia's most energy-intensive facilities. The design team evaluated a wide range of advanced energy-efficiency technologies using energy modeling and lifecycle cost analysis.

Sustainable Features: The largest energy consumer in the building is the ventilation air system that is required to maintain a safe laboratory environment; therefore, the laboratory HVAC system was a major focus of the redesign. Sustainable design features included in this building were variable-frequency drives for fan volume and pump control, a heat pipe energy recovery system with evaporative cooling, a chilled water thermal energy storage system, premium efficiency motors, a premium efficiency multiple boiler system, variable-air-volume fume hoods, energy management control systems (full direct digital control), sunshades and reflective glass, energy-efficient lighting, metering, and commissioning.

Financial Considerations: The table below shows the principal systems that added to first costs, the estimated cost savings, and simple paybacks. The total building cost was $28.5 million. The additional features described in the table added about 4% to the total cost but will quickly be returned in annual cost savings. Commissioning the building cost about $300,000 (about 1% of the building design cost) including internal staff time and the contractor's test engineers. After one year of operation, the annual energy consumption was 269,000 Btu/ft^2, which was even lower than the 341,000 Btu/ft^2 predicted by energy modeling studies.

Principal Systems Adding to First Costs and Estimated Cost Savings and Simple Paybacks

Energy-Efficiency Technology	Added Cost ($)	Added Cost ($/1000 ft^2)	Energy Savings ($/yr)	Energy Savings ($/ft^2)	Payback Period (yr)
Variable-frequency drives instead of inlet vanes for fan variable-volume control	109,600	726	61,700	259	1.8
Heat pipe energy recovery system with evaporative cooling	329,600	2182	31,800	211	10.4
Chilled water thermal energy storage system	239,500	1586	104,000	689	2.3
Premium efficiency motors	6,930	45	3,200	21	2.2
Premium efficiency, multiple-boiler system	8,750	58	8,200	54	1.1

Sources: Personal communication with R. Wrons, Sandia; and Laboratories for the 21st Century (2001).

2.3 Annual Water Cost Savings

Water efficiency can be achieved using a number of technologies that lower indoor water consumption (compared with the standard technologies available on the market), such as ultra-low-flow showerheads and faucet aerators, no-water urinals, and dual-flush toilets. Facilities can also lower potable water consumption by using nonpotable water for productive uses (e.g., using technologies that harvest rainwater or treat wastewater for re-use in various other applications in the buildings or on the site), better energy systems, recirculating water systems (instead of once-through cooling), leak detection and repair, and sustainable landscaping.

The costs for several water-saving features were estimated for the 20,000-ft^2 prototype building (see Table 2-4). All of the water-saving strategies analyzed have favorable economics, with payback periods from 2.8 to 0.3 years. If all the strategies in Table 2-4 were implemented, the total reduction in the annual cost of water for the building would be about $330, and the first-cost savings would be $590.

Table 2-4. Prototype Building Analysis: Cost Data for Water-Efficiency Features

	Incremental First Cost Per Unit	Incremental First Cost Per 1000 ft^2*	Annual Cost Savings Per 1000 ft^2*	Simple Payback (yr)
Ultra-low-flow showerhead	$4.99 per showerhead	$0.50	$0.33	1.5
Ultra-low-flow faucet aerators	$5.87 per faucet	$2.35	$8.14	0.3
Dual-flush toilets	$50.00 per toilet	$10.00	$3.58	2.8
No-water urinals	-$282 per urinal	-$42.30	$4.53	Immediate

* Costs were converted to a dollar value per 1000 ft^2 of gross building floor space to compare types of features. Cost values were rounded to three significant digits, although the convention of showing two numbers to the right of the decimal place (for cents) was maintained. Simple payback periods are shown in tenths of a year.

The following features were examined:

- **Ultra-low-flow showerheads and faucets.** The sustainable features examined in this study exceed the current standards required under EPAct. The current standards say showerheads cannot exceed 2.5 gallons per minute (gpm) at the typical building pressure between 40 and 80 pounds per square inch (psi). A more sustainable showerhead that uses 2.0 gpm was chosen for analysis in this document. Under current standards, kitchen faucets cannot exceed 2.5 gpm at 80 psi, and restroom faucets cannot exceed 2.2 gpm at 80 psi. For both the kitchen and restroom faucets, a 1.0 gpm model was chosen as the sustainable option for analysis in this document.
- **Dual-flush toilets.** Regulations mandate that toilets not exceed 1.6 gallons per flush (gpf). A dual-flush toilet has two flushing options: liquid flushing at 0.8 gpf and solid flushing at 1.6 gpf.
- **No-water urinals.** A no-water urinal that treats the waste chemically was compared with a typical water-using urinal.

Many Federal sites (military bases, national parks, U.S. Post Offices, and GSA buildings) have installed no-water urinals and other water-saving devices with great success. For example, the North Island Naval Air Station in San Diego, California, installed over 200 no-water urinals, and the

National Aeronautics and Space Administration's Jet Propulsion Laboratory in Pasadena, California, installed 250 units. The University of California, Los Angeles (2000) performed a study, examining the performance of a urinal that uses no water compared with a urinal that uses 3 gpf. The study compared the following parameters to determine how well the no-water urinal performed: usage, bacterial growth and odor, and lifecycle cost. The study concluded that the no-water urinal performed better than its specifications. In the tests conducted, no odors were detected.[24]

Many other water-saving approaches are available, including process-oriented technologies and site-specific techniques, for which costs are difficult to quantify generically as was done for the low-flow appliances described above. However, these measures are often very cost effective:

- **Cooling towers** are often one of the largest water users for large office buildings, hospitals, and industrial facilities. As water is evaporated through the tower, dissolved solids remain in the system and build up over time, requiring water to be purged from the system through what is known as "bleed-off." Maintaining water quality is key to saving water in cooling towers and reducing bleed-off. Chemical treatment, side stream filtration, and ozonation can help maintain proper water quality and reduce bleed-off and water consumption.
- **Single-pass cooling equipment** can also be a major water user in Federal facilities. When the equipment is modified to a closed loop system, the water can be recycled rather than discharged down the drain, saving up to 40 times the water required for heat removal from the equipment.
- **Boiler and steam systems** are often found in large Federal facilities such as central plants, hospitals, large office buildings, barracks, and industrial process plants. Proper maintenance of steam traps and condensate return and reduction of blow-down by maintaining proper water quality in the system can help reduce water use in these systems.
- **Leak detection and repair of water distribution systems** can provide large water savings with very quick payback, especially for military bases that have old (pre-1940s) systems. Such systems can reduce water losses and operating costs and can increase understanding of system operating characteristics. Typically, leak detection is done as part of a comprehensive water audit to help determine the source of unaccounted for water consumption at the site.
- **Sustainable landscaping** using plants native to a region (including drought-resistant plants) reduces (or eliminates) the need for irrigation water. This is discussed further in Section 2.4.

Case Study 2-3 discusses the water savings achieved at a facility in Ann Arbor, Michigan, by using closed-loop cooling and other measures. Although this example demonstrates savings in a retrofit situation, many of these techniques can be used in constructing new facilities, especially those housing laboratory or other process equipment with high water and energy needs.

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[24] The chemical cartridge (a device in the urinal's drain that traps odors while allowing urine to pass through) performed with no maintenance problems over 7,000 uses (the guaranteed number of uses for each cartridge) and did not clog during the testing period. The no-water urinal did not have a greater bacterial growth level than the conventional urinal. The study measured concentrations of ammonia, the chemical that produces the offensive odors in urinals. No significant difference existed between ammonia levels in the vicinity of the two urinals and neither approached the level that can be detected by humans. In a retrofit scenario, the economic analysis performed for the no-water urinal indicated a simple payback of less than three years and an annual internal rate of return from 37% to 61% (the range is based on population densities of different types of buildings).

Case Study 2-3: U.S. Environmental Protection Agency (EPA) Facility in Michigan Reduces Water Consumption by 80%

The National Vehicle and Fuel Emissions Laboratory underwent a major retrofit to reduce energy and water consumption using an Energy Services Performance Contract (ESPC). The facility reduced its water consumption by 80% over baseline conditions, saving about $140,000 annually through a complete upgrade of the facility HVAC system, installation of chilled and hot water recycle loops, and use of other conservation measures.

Project Description: This water-intensive facility is a 30-year-old, 175,000-ft^2 building in Ann Arbor, Michigan, and is owned and operated by the EPA. The building houses offices, testing laboratories, and support spaces. The EPA, with support from DOE's FEMP, awarded an ESPC to NORESCO in 1998 for a comprehensive upgrade of the energy systems; this upgrade also significantly reduced water consumption and costs.

Approach to Sustainable Design: The building's main functional space is a high-bay research space where vehicles and engines are tested. Testing activities consume a high level of both energy and water. Before the retrofit, the facility had an annual utility bill of over $1 million, and annual water consumption averaged 31 million gallons from 1993 to 1995. During that time, single-pass cooling water (for the engine test cells, air compressors, and process chillers) accounted for about 75% of total facility water use. Cooling tower makeup water accounted for an additional 10% of the facility's water use.

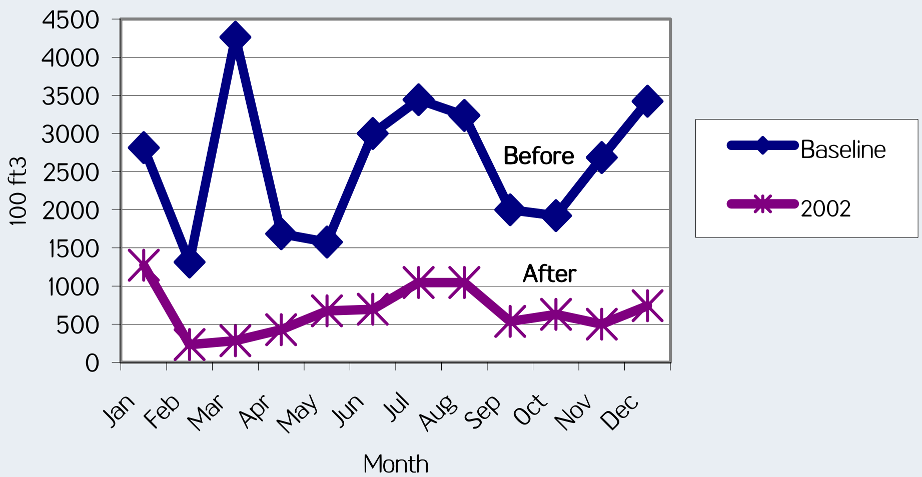
The facility engaged in an ESPC with the following objectives: reduce energy consumption, emissions, and energy costs through energy conservation measures (ECMs); exceed Federal energy reduction mandates; eliminate chlorofluorocarbons (CFCs); reduce water consumption; and provide a simple payback of less than 10 years on the contractor's capital expenditure. Analysis and audits resulted in 11 individual ECMs. Although most of the ECMs focused on energy savings, many of the energy-savings measures also significantly reduced water use. One ECM specifically focused on water conservation by converting once-through cooling systems to closed-loop systems, recirculating chilled water to cool process loads at the facility, and significantly reducing water consumption.

Sustainable Features: Key components of the ESPC included replacing 36 rooftop air-handling units; replacing existing equipment in the central heating and cooling plant with two new direct-fired chiller-heater absorbers, one new high-efficiency condensing boiler, and two new cooling tower cells with variable frequency fan drives; and adding a new pumping system. The upgraded chilled water system was sized to replace the once-through cooling water with recirculated chilled water.

Before the ESPC, the single-pass cooling system used about 23 million gallons of water per year; the upgraded cooling plant with the recirculated chilled water loop reduced water consumption by over 95% to fewer than 1 million gallons. In addition, before the ESPC, boiler makeup water accounted for about 1 million gallons of facility water per year; but after replacing the old system with high-efficiency condensing boilers and installing a new hot water piping distribution system, the hot water loop makeup now accounts for only 7200 gallons of water per year. In addition to the ESPC, the facility has used other water-saving best management practices, including public information and education programs to educate employees on water conservation topics, audits for leak detection and repair, a water-efficient landscape that uses no irrigation water, and low-flow fixtures and faucets.

Financial Considerations: The figure below shows water consumption before the measures were implemented (averaged over 1993 to 1995) and after the implementations (in 2002). About 25 million gallons (3.3 million ft^3) of water were saved annually. Because water and sewer costs, combined, are about $4.20 per 100 cubic feet in Ann Arbor, the measures reduced total water and sewer costs by about $140,000 annually. Associating a precise capital cost directly to this annual water cost savings is difficult because of the synergy between the energy and water savings. For example, the ESPC replaced 36 rooftop air-handling units that, before the retrofit, operated in a single-pass mode. The new units use enthalpy recovery wheels and recirculate 80% of the air. This change reduced water consumption because central plant heating and cooling requirements have been dramatically reduced. This reduction created the opportunity to replace the cooling tower with two smaller cells, significantly reducing water use in the tower. In addition, the plant no longer has to humidify single-pass air in the winter.

The ECM that was directly related to water reduction (implementing the recirculating chilled water loop) cost about $129,000 in first costs and saved over $48,000 in water costs in 2002. If these savings are achieved each year, the payback period will be 2.7 years.



Water Consumption Before and After ECM Implementation

Sources: Personal communication with S. Dorer, Facility Manager at the National Vehicle and Fuel Emissions Laboratory, Ann Arbor, Michigan; R. Sieber, ERG (consultant); and P. Wirdzek, EPA Labs21 Program Manager.

2.4 Lower Costs of Facility Maintenance and Repair

Sustainable design aims to increase durability and ease of maintenance. For example, the service areas within sustainable buildings should be designed with enough space to allow easy access to mechanical equipment. Easy access will reduce the cost of scheduled maintenance, repair, and eventual replacement. Other approaches can also reduce annual maintenance costs using sustainable design:

- Using durable, long-lasting sustainable materials can decrease maintenance and repair costs. For instance, cement companies have tested fly ash and slag concretes and found that, if properly cured, they have greater strength and durability than concrete made from normal Portland cement.[25]
- Using low-emitting paints offers excellent durability according to some vendors.[26]
- Designing buildings with areas for efficient and convenient collection of recyclable materials, such as paper, plastic, and glass, can reduce annual waste disposal costs (if recycling costs are lower than normal charges for municipal solid waste).
- Using fluorescent lamps reduces labor costs for maintenance. These lamps last about 10,000 hours as opposed to 1,000 hours for incandescent lamps. Therefore, about 10 lamp changes (and the associated labor costs) are avoided by using fluorescent lamps.
- Lightening roof color can prolong a roof's lifetime (in addition to reducing summertime heat gains and air conditioning costs) (Rosenfeld et al. 1995).
- Using recycled carpet tiles, which can be removed and replaced individually, reduces the need to replace carpet.
- Using sustainable landscaping techniques typically decreases lawn mowing, fertilizer use, and irrigation and has short payback periods (e.g., in the prototype building example below, the payback was less than one year).
- Managing stormwater through "natural" methods such as drainage ponds that also serve as habitats for wildlife, rather than storm sewers, often exhibits favorable lifecycle costs.

Table 2-5 shows the first costs and annual cost savings of two specific site-related strategies that reduce annual maintenance costs using the same prototypical building described in the previous sections. Together, the strategies increase first costs by about $5600, which is quickly repaid through maintenance cost savings of about $3600 annually.

Table 2-5. Prototype Building Analysis: Costs for Sustainable Siting Features

	Incremental First Cost	Incremental First Cost Per 1000 ft^2*	Annual Cost Savings Per 1000 ft^2*	Simple Payback (yr)
Sustainable stormwater management	$3140	$157	$28.20	5.6
Sustainable landscape design	$2449	$122	$152	0.8

* Costs were converted to a dollar value per 1000 ft^2 of gross building floor space so types of features could be compared. Multiply costs per 1000 ft^2 by 20 to obtain total costs for the building. Cost values were rounded to three significant digits, although the convention of showing two numbers to the right of the decimal place (for cents) was maintained. Simple payback periods are shown in tenths of a year.

[25] For example, see http://www.lafargenorthamerica.com/lafargeNA.nsf/CementSplash?OpenForm.

[26] For example, see http://www.duron.com/products-generalinfo-interior-genesis.html.

The two site-related strategies shown in Table 2-5 are described as follows:

- **Sustainable stormwater management.** An integrated stormwater management system combines a porous gravel parking area with a rainwater collection system, where rainwater is stored for supplemental irrigation of native landscaping. This porous, gravel-paved parking area is a heavy load-bearing structure that is filled with porous gravel, allowing stormwater to infiltrate the porous pavement (reducing runoff) and to be moved into an underground rainwater collection system. The water can be used to supplant fresh water from the public supply for uses that do not require potable water. This sustainable system is compared with conventional asphalt parking area and a standard corrugated pipe stormwater management system without rainwater harvesting.
- **Sustainable landscape design.** A mixture of native warm weather turf and wildflowers is used to create a natural "meadow" area. This strategy is compared with traditional turf landscaping of Kentucky blue grass, which requires substantially more irrigation, maintenance, and chemical application.

Although the particular sustainable stormwater system used for the prototype increases the total construction cost by a little over $3000 (about 0.1% of total building construction cost), it saves over $500 annually in maintenance costs because less labor is required for patching potholes and conducting other maintenance on an asphalt lot. The resulting payback period is less than six years. The sustainable landscaping approach shows even more favorable economics; the incremental first cost is nearly $2500, but this is repaid in less than one year with an annual O&M costs savings of $3045 in avoided maintenance, chemical, and irrigation costs. (See Appendix D for more information on how these costs were calculated.) Case Study 2-4 shows a real-world example of the cost savings associated with sustainable landscaping.

2.5 Lower Churn Costs

In today's work environment, employees are increasingly relocated within existing buildings to improve organizational effectiveness or as a result of downsizing, reorganization of the business, or business growth. A survey conducted by the International Facility Management Association (IFMA) and published in 1997 determined that, on average, 44% of building occupants move within a given year. This is called the "churn rate."[27] In government buildings, the churn rate appears to be somewhat lower – 27%. (The survey included 20 government respondents.) The survey found that the churn rate has been increasing over time.

Moves are expensive. According to IFMA (1997), the average move in the government cost $1340 (per person). The cost of a move depends on the extent to which the facility must be modified to accommodate the changes. IFMA found that if new walls, new or additional wiring, new telecommunications systems, or other construction is needed to complete the move, the average cost in a government setting is $3640 (IFMA calls this a "construction" move). However, if no furniture is moved, no wiring or telecommunication system changes are required, and only files and supplies are moved, the average cost in a government building dropped to $166 (IFMA calls this a

[27] The churn rate is defined as the total number of moves made in a 12-month period, divided by the total number of occupants, multiplied by 100 (to obtain a percentage).

Case Study 2-4: Argonne National Laboratory's Central Supply Facility Reduces Costs Through Sustainable Landscaping

This case study demonstrates how native landscaping can reduce both installation and O&M costs of landscaping a Federal facility. The cornerstone of this design is the native trees, which require no irrigation system, provide shade to the building, and require very little maintenance compared with a traditional landscape of sod and large non-native trees.

Project Description: The facility – built in 2001 in Argonne, Illinois – is Argonne's shipping and receiving warehouse. It was built onto an existing structure.

Approach to Sustainable Design: The design and integration team for the facility began incorporating design review early to ensure that all technical aspects were properly evaluated. Other aspects vital to the project's success included educating the building occupants about sustainable features and training the maintenance staff.

Sustainable Features: Argonne incorporated many sustainable design features into the facility. One hundred immature native trees were planted in small groups surrounding the facility. The trees were much smaller than the larger mature trees traditionally planted on Argonne grounds. Planting smaller trees helps reduce both the stress on the trees at planting and their long-term water requirements. Native turf was seeded on the grounds instead of planting traditional sod, thereby eliminating the need for an irrigation system.

Other sustainable features included recycled building materials such as concrete block, carpet, structured steel, lumber, ceiling tiles, partitions, and gypsum board. In addition, efficient water fixtures in the restrooms, low VOC paint, an energy-efficient mechanical system, high-performance windows, and a rooftop rain catchment system were integrated in the sustainable design. The facility was LEED-certified in spring 2002.

Financial Considerations: The native landscaping significantly reduced installation and O&M costs. Installation costs were reduced because smaller holes were required to plant smaller trees. The 100 native trees that were planted on the grounds had the same estimated cost as 40 mature trees. Seeding native grass on the grounds was a much less labor-intensive practice than laying sod. Sod also requires large amounts of water to saturate the ground so the sod can adapt to the new environment. Seeding with native grass and eliminating the irrigation system saved Argonne about $11,000 in first costs.

In one growing season, the trees and seeded grass became well established and currently do not require supplemental water to remain healthy. If large non-native trees and sod had been used, regular watering would have been required for two growing seasons and supplemental water would have been required during droughts. The native landscaping reduced water requirements by an estimated 40% within the first two growing seasons and reduced the need to mow and fertilize the native grass. Overall, the native landscape reduces O&M costs by an estimated 50% compared with more traditional landscape.

Sources: Personal communication with K. Trychta, Argonne's Pollution Prevention Coordinator.

"box" move).[28] If existing furniture is reconfigured or furniture is moved or purchased but only minimal telecommunication reconfiguration is needed, the government cost averaged $613 (a "furniture" move).

To reduce churn costs, many high-performance, sustainable buildings include a raised floor system that creates an underfloor plenum used for HVAC air distribution and modular power cabling and telecommunications/data systems. The HVAC system and cables in the underfloor plenum typically are accessible through individual, movable floor tiles. These raised-floor systems also enable personal controls to be used, allowing each occupant to control the level of ventilation, temperature, and lighting levels at his or her own workstation (the benefits of personal controls on occupant productivity, health, and well-being are discussed in Section 3). In addition, sustainable buildings often use removable partitions in place of permanent walls.

Using raised floor systems and removable partitions can significantly reduce churn costs. No ductwork revisions or other complex construction is needed to alter workstation configurations. The access floor system, together with floor diffusers, allows the layout of the space to be modified with very little lost work time. The move costs in a building with a raised floor and movable partitions would be closer to the box or furniture moves described above ($166 to $613 per person) than to the construction move ($3640 per person).

When using underfloor air systems, local workstation air conditioning control devices can be relocated in less than five minutes with a screwdriver being the only tool required.

Source: Shute (1992)

The first costs of a building with a raised floor system and underfloor HVAC/cabling will depend on the many factors specific to the building, but estimates documented by Loftness et al. (2002) indicate that the first costs are about the same as (or only slightly higher than) those in a building with a traditional acoustical tile or drywall ceiling system.[29] The major additional cost of such a building is the raised floor itself – from $3 to $10/ft^2 depending on manufacturer, quality, and integrated components (Loftness et al. 2002) compared with installed acoustical ceiling tile, which typically costs $1.49 to $2.31/ft^2 (RS Means Company, Inc. 2002). However, the additional costs for the raised floor would most likely be offset by a lower first cost of the underfloor air-handling system compared with the traditional ceiling air-handling systems. Milam (1992) states, "Most HVAC equipment installation occurs below the raised floor, therefore laborers perform little work on ladders, platforms, or hoists. . . . This allows substantial increases in laborer productivity that corresponds to savings in labor costs." These underfloor air-handling systems also usually have smaller piping, pumps, and refrigeration equipment; and most of the ductwork is eliminated.

In addition to HVAC savings, the underfloor system also reduces first costs of power distribution, receptacles, data communication devices, and labor for installing cabling. Some evidence exists that underfloor HVAC systems also reduce annual energy costs by 20% to 35% (Loftness et al. 2002). See the comprehensive report by Loftness et al. (2002) for a complete explanation of the

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[28] Using the entire population of buildings surveyed by IFMA (1997), including various types of private-sector enterprises, the average cost per move was $1207; the average cost of a construction move was $4194; the average cost of a box move was $149; and the average cost of a furniture move was $523.

[29] One study (Wilson 1998) of a private-sector office building in California estimated a $2.70/ft^2 *decrease* in first cost for the access floor system (compared with an overhead system). Part of the estimated cost reduction in this study was from using carpet tiles in the building with the access floor versus rolled goods in the traditional building, which decreased the cost of the access floor by almost $100,000. However, given that the traditional building could also use carpet tiles, the cost differential of $2.70 seems somewhat overstated. If the carpet difference were eliminated from the estimate, the cost of the building with the access floor would have been about the same as that of the standard ceiling HVAC distribution system.

costs and benefits of these underfloor systems. In addition to churn cost savings, the use of underfloor systems and movable partitions also saves materials and material costs during moves.

For the prototype 20,000-ft^2 office building, which hypothetically houses about 100 occupants, building owners could save from $35,000 to $81,000 in churn costs[30] if the building were outfitted with an underfloor system and moveable wall partitions instead of traditional systems. These savings likely could be achieved with little additional first cost.

> *"The cost of an intelligent building with a good quality access floor, a modular electrical distribution system and under-floor air is very close to the cost of a traditional poke-through building (less than 1% greater)."*
>
> Source: York 1994 (cited in Loftness 2002)

Research Summary 2-1 provides data on churn costs in an actual government office building with 1,500 work stations (the Rachel Carson State Office Building in Harrisburg, Pennsylvania). This study indicates that a high-performance green building with a raised floor could save over $800,000 annually (compared with one without the raised floor) in a large building that has a 25% annual churn rate (a savings of $2250 per person moved). The costs of churn are often neglected when the lifecycle costs of a building are estimated. This evidence indicates that such costs should be more seriously considered.

2.6 Lower Absenteeism and Improved Productivity

Many studies, which will be described in this section, have shown that building occupants respond to some of the features of sustainable buildings by working more productively, making fewer errors, and being absent less often, thus reducing labor costs.

Figure 2-1 shows that, as a fraction of total expenditures, labor costs in the government far exceed construction, energy, or other annual costs,[31] so measures that positively influence worker performance and absenteeism rates could have a much higher financial impact than energy efficiency or other measures affecting operating costs.

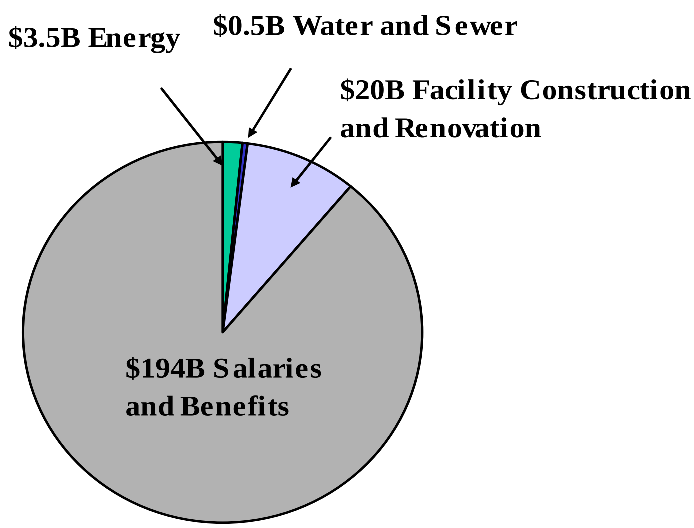

Figure 2-1. Annual Federal Government Costs

[30] These figures assume 27 moves at a savings per person of about $1300 (the difference between the average government move and the box move) to $3500 per move (the rough difference between a construction move and a box move). Although Loftness et al. (2002) estimate somewhat lower cost savings of $100 to $500 per move, the cost savings of $2250 per move estimated for the case study of the Rachel Carson State Office Building is at about the midpoint of the estimated range used in these figures.

[31] Sources for data in Figure 2-1 include Office of Personnel Management website http://www.opm.gov/feddata/02factbk.pdf and Federal Facilities Council (2001). Note that personnel costs are for civilians only (including civilian employees of U.S. Department of Defense). Energy and other costs include military facilities.

Research Summary 2-1: Pennsylvania's Department of Environmental Protection Estimates the Cost of Churn

The Pennsylvania Department of Environmental Protection (DEP) took advantage of its need to relocate 700 of the 1500 employees in the Rachel Carson State Office Building (RCSOB) in Harrisburg, Pennsylvania, to estimate the cost of churn. The actual cost of the moves in RCSOB, which did not have a raised floor system, was compared with the estimated churn cost in a new high-performance "green technology" office – South Central Regional Office Building (SCROB) – where employees had similar functions and space requirements. The comparison shows that using raised floor systems in sustainable buildings can reduce churn costs by 90%.

Research Team: Staff members of the Pennsylvania DEP; J. Toothaker, Lead.

Research Setting: The RCSOB is a traditional 16-story office structure with a central service core. It is equipped with carpet tile, a cellular floor for electrical and telephone/data distribution, modular furniture, full-height demountable walls, and mechanized central file systems on all floors. However, it does not have a raised floor. Its dropped ceiling contains drop-in fluorescent light fixtures, sprinklers, and a variable-air-volume HVAC ceiling distribution system; the building also has a hot water perimeter heating system. Exterior walls are glass, and the central core provides restrooms, elevators, electrical rooms, telephone/data rooms, and communicating stairways on each floor.

The opportunity to study churn costs in this building resulted from a requirement to reconfigure and relocate 700 of the 1500 employees in this facility to reorganize one agency into two agencies. Workstations and common areas had to be reconfigured. Two floors were completely reconfigured to accommodate about 240 work areas, with the remaining 460 workstations scattered throughout the remaining twelve floors. This involved the following:

- Dismantling and reconstructing private offices
- Unwiring, cleaning, and reconfiguring the modular furniture and cleaning the chairs
- Reconfiguring variable-air-volume boxes, lights, and sprinkler heads in the ceilings
- Reconfiguring central file equipment and the electrical and telephone/data connections on each floor
- Cleaning or painting all surfaces in the reconfigured areas
- Relocating personal computers and peripherals.

Components within the SCROB's Raised Floor System

The photo shows the plenum space below the floor surface and the air diffuser, phone modem/fax mounting, and power strip on top of the carpet tile.

All of this work was done using competitively bid contracts, with about 50% of the labor performed at straight time during the workday and the remainder at premium pay at night and on weekends.

DEP had just completed SCROB, a high-performance "green technology" office with a raised floor system. This project allowed the team to compare churn costs between the two types of offices. The primary difference in the churn costs between the two buildings is the use of a raised floor system to create a floor plenum for HVAC air distribution, which also houses the modular power and telephone/data distribution systems. This raised floor plenum system with its individual floor tiles, which are movable and easy to relocate, allows easy access to the floor HVAC diffusers and power telephone/data cables. When the raised floor system is used, systems furniture and demountable walls are no longer wired together, which further reduces cost and lapse time for churn.

Methodology: The comparative evaluation consisted of a methodical review of the actual unit costs and elapsed time needed for each contracted activity for the RCSOB moves. Then, the DEP estimated the cost and time needed for each of the same activities for a comparable move in the SCROB.

Results: The cost for the RCSOB project, which reconfigured 700 workspaces (including both offices and open workstations) was about $1.777 million or $2538 per person. The project's actual renovations and reconfigurations were completed in about three months.

DEP conducted a detailed analysis of the move costs, including all materials and labor for each contracted activity. Each contracted activity in the new building with the raised floor (SCROB) was estimated. The cost and length of time to physically reconfigure work spaces were estimated to be about 90% lower in SCROB than in RCSOB. The table below shows the calculations (for ease of presentation, numbers and percentages were rounded).

Comparison Analysis of the Moving Costs in RCSOB

	Actual Costs in the RCSOB	Hypothetical Costs Had A Raised Floor Been Installed in RCSOB
Building type	Conventional office facility	High-performance green building (raised floor)
Number of work spaces	1500	1500
Annual churn rate	25%	25%
Number of work spaces reconfigured annually	375	375
Cost per reconfiguration	$2,500 (based on actual data)	$250 (estimated based on situation in SCROB)
Annual cost of churn	$937,500	$93,750
Churn cost savings	Not applicable	$843,750

The RCSOB was completed in 1993 at a constructed cost slightly over $40 million. If the facility had been designed and built with a raised floor, lower churn costs equal to over 2% of its constructed cost per year could have saved DEP about $7.6 million since the building's occupancy in 1993.

Source: Personal communication with J.S. Toothaker, former Bureau Director, DEP, Commonwealth of Pennsylvania. Mr. Toothaker managed the 700-employee move in the RCSOB and compared the actual and estimated costs between the two facilities based on his personal participation and knowledge of the facilities. Mr. Toothaker was the principal developer of the Building Green in Pennsylvania Program.

One key research study (Milton et al. 2000) that examined the relationship between absenteeism and ventilation rates is highlighted in Research Summary 2-2. This study assigned dollar values to the benefits of better ventilation and estimated potential annual cost savings of about $25,000 per 100 employees, resulting from a one-time investment in better ventilation systems of $8000 per 100 employees. This research strongly implies that designers should pursue the goal of good indoor air quality simultaneously with the goal of energy efficiency.

Research Summary 2-2: Improved Indoor Air Quality Reduces Absenteeism Costs

A research study assessed sick leave for 3720 hourly workers in a large manufacturing firm in Massachusetts to determine the relationship between absenteeism and factors such as ventilation, humidity, and indoor air quality. The study showed that $24,444 per 100 employees could be saved annually with a one-time investment in improved ventilation of $8050 per 100 employees.

Research Team: The research team included D.K. Milton of the Harvard School of Public Health, P.M. Glencross of the Harvard School of Public Health and Polaroid, and M.D. Walters of Polaroid.

Research Setting: The research setting was 40 buildings and 115 independently ventilated work areas.

Methodology: Sick leave data were gathered from corporate records (excluding extended sick leave or short-term disability). Other data gathered on employees included age, gender, race, shift, job code, years of employment, and the employee's primary work area (building and floor).

The final analysis focused on clerical workers to control for the potential effects of occupational factors. The analysis also used existing corporate records to identify building characteristics and indoor environmental quality complaints. The study gathered the following data on each building in the study:

- Presence of devices to humidify supply air such as steam, spray, and finfill humidifiers
- Formal complaints to the corporate environmental health and safety office and remediation efforts
- Ventilation ratings for each floor – categories as either "moderate" (about 12 L/s) or "high" (about 24 L/s)
- Additional air quality data, including endotoxin and total airborne bacteria counts, culturable bacteria, culturable fungi, spore counts, and VOCs.

Key Findings: The study's results included the following:

- Moderate ventilation and use of humidifiers were associated with more total sick leave as well as more short-term sick leave.
- Of the short-term sick leave, 35% was attributed to lower ventilation rates, translating to 1.2 to 1.9 days of increased sick leave per person per year.
- Reductions in sick leave from improved ventilation were similar to reductions during flu season due to influenza vaccination.
- Respiratory illnesses caused by airborne viruses or bacteria could be effectively reduced with ultraviolet irradiation of air near the ceiling and with increased ventilation.
- Economic analysis showed that investing $8050 per 100 employees in improved ventilation could reduce sick leave by $24,444 per 100 employees (from $39,950 to $15,506, per 100 employees).

Source: Milton et al. (2000).

Another study of 11,000 workers in the Netherlands found that absenteeism from "sick building syndrome" is likely to be 34% lower when workers have control over their thermal conditions (Preller et al. 1990). A comprehensive study of methods to improve indoor environmental conditions estimated that the value of improved productivity (including lower absenteeism) of office workers could be as high as $160 billion nationwide (Fisk 2000).

Measuring productivity is relatively straightforward for simple information processing tasks, such as data entry and forms processing. For most knowledge workers, however, productivity is more difficult to measure because the outcomes are highly variable, often elusive, and difficult to document.[32] Furthermore, much knowledge work is valued for its impact rather than its output. "Impact" refers to the value of the work (as indicated by an idea, concept, plan, or policy) to the organization. Because of these difficulties, the building blocks or precursors of productivity are often measured rather than work output. These blocks or precursors include specific kinds of tasks associated with knowledge work performance, such as attention, reading comprehension, creativity, and logical thinking.

Performance benefits resulting from sustainable building features are described below. The evidence presented on performance benefits is drawn primarily from research conducted on occupants of actual buildings rather than from laboratory studies. The studies cited are from peer-reviewed publications or conference proceedings and include publications in building science, lighting, environmental psychology, and human factors. Taken as a whole, the studies show a cluster of building factors associated with improved performance: good ventilation; glare-free lighting; personal control over temperatures and ventilation; and good maintenance and cleaning, especially of the HVAC system. These factors appear to influence performance by reducing illness symptoms that interfere with work, by increasing alertness and reducing fatigue, and by reducing visibility problems.

- **Performance on clerical and word processing tasks.** Much of the research on work performance has been conducted in experimental settings where stimuli can be carefully controlled, although a few studies have been conducted in actual work settings. For example, a field simulation study tested performance on a word processing task in an office with and without a 20-year-old carpet (Wargocki et al. 2000). The study found that workers' performance was 6.5% better without the carpet. All other factors, such as ventilation and temperatures, were held constant. Therefore, the results are due to air quality differences associated with the old carpet. A frequently cited field study (see Research Summary 2-3) conducted in an insurance agency building found a 16% increase in performance on forms processing when the company moved into a new building (Kroner et al. 1992). The measure was actual work productivity, not performance on simulated tasks. Of the overall 16% increase in productivity, 3% was attributed to using personal controls over temperature and ventilation and 13% was attributed to generally improved building quality and interior design, including improved daylight, views of a natural landscape, better access to windows by workers, and increased visual openness of the environment. In a review of building studies, Wyon (1996) estimated that providing workers with temperature control of just three degrees (plus or minus) would result in productivity increases of 7% for typical clerical tasks.

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[32] In some cases, researchers have attempted to associate a dollar figure on the absenteeism and other occupant benefits. The Center for Building Performance and Diagnostics within the School of Architecture at Carnegie Mellon University has collated a large body of research into a tool called the Building Investment Decision Support. This tool allows a user to generalize the results of a particular research studies to estimate potential dollar benefits at the user's facility.

Research Summary 2-3: Personal Environmental Controls at West Bend Mutual Insurance Company Improve Worker Productivity

This study assessed the impact of workstation personal controls and other features typically associated with sustainable buildings on worker productivity using an existing performance monitoring system. When the organization moved into the new building, overall productivity increased by 16%. Of that, 3% was associated with the system that provided personal control over temperature, air velocity/direction, task lighting, and sound masking.

Research Team: Rensselaer Polytechnic University.

Research Setting: The research took place in an existing building and a new building that had personal controls at most of the workstations.

Features of the Old Building:

- 61,800 ft^2 for 400 workers (considered crowded)
- No task lights; ceiling lights were 4-ft recessed fluorescent fixtures
- Three different air distribution strategies
- Located in the center of town
- Managers located along window wall; workers in central core.

Features of the New Building:

- 149,800 ft^2 for 400 occupants and many amenities (conference rooms, instructional rooms, auditorium, cafeteria, exercise room, and outdoor patio)
- Skylights
- Indirect lighting
- 370 workstations with personal control over temperatures, air velocity and direction, task lighting. and sound masking
- 92% of workers on the perimeter with access to daylight and views (versus 30% in old building)
- Location in a prairie landscape setting with trees and a pond.

Personal Control System

Methodology: Data were gathered for workers in the accounting and underwriting departments for 27 weeks before they moved into the new building and 51 weeks after the move. Data included the number of files of each type that each employee processed during the week. To separately account for the effect of the personal controls (versus the potential impacts of other building or organizational changes), components of the control system were randomly disabled during the last 24 weeks of the study – air velocity, air temperature, and the radiant panel.

Key Findings: The study's results included the following:

- The combined effect of the new building and the personal controls produced a median increase in productivity of about 16%. Personal controls accounted for a 3% increase and the new building and setting accounted for 13%.
- Overall satisfaction increased from 46% in the old building to 75% in the new building.
- Satisfaction with the new building's temperatures, air quality, noise, and lighting all improved.

Sources: Kroner et al. (1992).

- **Attention and concentration.** Studies have also found that certain sustainable design features improve performance on tasks requiring high levels of attention. For instance, a study by Nunes et al. (1993) found performance increases from 7% to 30%, depending on the task. The variability in performance was attributed to differences in ventilation levels and the consequent impact on illness symptoms. Lower levels of ventilation were linked to higher reports of symptoms, which in turn were associated with poorer performance. Workers reporting symptoms worked 7.2% slower on a vigilance task and made 30% more errors on a digit substitution task.

  Numerous studies show performance problems from increases in noise distractions and interruptions (Fried et al. 2001; Jones and Norris 1992). Decreased performance is more likely for complex, creative tasks and tasks relying heavily on short-term memory, such as writing and computational work. Many of the factors that increase noise distractions (e.g., smaller workstation sizes, increased densities, and reduced use of carpeting or other sound-absorbing materials) are commonly used to achieve sustainable goals such as increased access to daylight and views and improved flexibility. Therefore, sustainability-oriented designers should consider both positive and negative impacts of various design features in the final design.

- **Complex cognitive performance.** Improved performance on logical thinking tasks has also been reported in a review of interior environmental quality (Wyon 1996). Wyon cites studies in Sweden showing a 2.7% increase in logical thinking associated with personal control over temperatures. The impact of temperature conditions on performance is complex, with some studies showing improved performance on creativity and memory tasks with slightly elevated temperatures and with the opposite shown for concentration and logical thinking, which may benefit from slightly cool temperatures (Wyon 1996).

- **Organizational level performance.** Most productivity studies focus on individual level work. However, there is evidence that building design can influence high-level organizational outcomes. An analysis of the Total Quality Management (TQM) metrics data used by Herman Miller to assess its performance shows small increases of 0.22% in overall productivity and increases of 1% to 2% on other indicators after the organization moved into a new sustainable building (Heerwagen 2000). (This study is described in Section 3.2.)

- **Self-ratings of productivity.** Research in office settings often resorts to employees rating their own productivity (i.e., self-rating) because of the difficulty of obtaining actual work outputs. Although self-measures tend to be overestimated, when the measure is used in a comparative manner to assess responses to baseline environments and change initiatives, they provide useful information (Leaman and Bordass 2001). They also are fairly easy to administer.

  Studies using self-assessments of productivity have found strong relationships to thermal and air quality factors in line with studies of actual performance, as noted above. In a review of occupant surveys over a 20-year period in the United Kingdom, Leaman (1999) reports that comfort and perceived productivity are greater in buildings where occupants have more control over the environment and in mixed-mode buildings that have both natural ventilation and air conditioning. Two studies of more than 11,000 workers in 107 buildings in Europe also found increases in perceived productivity in buildings that provided workers with control over temperature and ventilation conditions (Preller et al. 1990).

  Similar results are reported for an intervention study in Canada (Menzies et al. 1997). The study consisted of two groups of workers in a mechanically ventilated building. The "intervention" group was given control over the ventilation at the workstation with a handheld infrared device that could regulate the amount and direction of air flow from four-inch air outlets in the ceiling. The "control" group was not given any control over ventilation. Workers in the intervention group said their productivity increased by 11% at 16 months after the study. In contrast, workers in the control group said their productivity decreased by 4%. Environmental assessments of the two spaces showed that air velocity in the intervention space tripled and that both temperature and ventilation variability across the space increased also (an indication that workers were making adjustments according to their personal preferences and needs).

A field study of electric lighting systems found increased self-ratings of performance with indirect lighting due to decreased glare on computer screens as well as reduced eye problems (Hedge et al. 1995).

2.7 Other Economic Benefits to the Building Owner

Federal agencies, as well as sustainable building owners in the private sector, are likely to accrue economic benefits as a consequence of a sustainable facility's environmentally and socially conscious image and its positive impacts on building occupants, prospective employees, the community surrounding the facility, and society as a whole.

Research has been conducted on a few important topics related to sustainable buildings, from which inferences can be drawn about the building owner's economic benefits, which are sometimes less direct and/or longer term than the benefits described in Sections 2.1 through 2.6. This section discusses several of these somewhat indirect or longer-term economic benefits:

- Better worker retention and recruitment
- Lower cost of dealing with complaints
- Decreased risk, liability, and insurance rates
- Greater building longevity
- Better resale value
- Ease of siting
- Strategic and economic value of an improved image.

2.7.1 Better Worker Retention and Recruitment

The environmentally conscious image associated with an agency that builds or occupies sustainable buildings may result in employee pride, satisfaction, and well-being that translate into reduced turnover, improved morale, and a more positive commitment to the employer. These effects may have a big financial impact by reducing labor replacement and training costs. In addition, these effects transfer to the building owner a reputation as a desirable employer, which in turn creates valuable leverage for attracting, recruiting, and retaining talented employees. Moreover, developing a high-caliber workforce ultimately results in additional long-term performance benefits described above. While rigorous statistical studies on employee retention and attraction in sustainable facilities have not been conducted, many studies have shown increased feelings of well-being associated with sustainable buildings (see Section 3.2). The retention and attraction aspects are a logical (although not fully proven) extension of feelings of well-being.

In his recent book, *The Sustainable Advantage*, Willard (2002) argues that sustainability, as a corporate strategy, will become more common if it can be linked more convincingly to business value. As Willard argues, organizations that make sustainability a core value may benefit by being able to attract and retain young workers who also value the environment and who will therefore be more willing to work harder to ensure that the organization's environmental values are realized. Willard also acknowledges that the work environment itself may influence attraction, retention, and productivity by creating better working conditions.

2.7.2 Lower Cost of Dealing with Complaints

When building occupants are uncomfortable – typically from a room temperature that is too hot or too cold – building maintenance engineers spend hours dealing with complaints. In a study of the costs of dealing with discomforts, researchers estimated that efforts to increase comfort could decrease the labor costs of responding to complaints by 12% (Federspiel 2001). The data from the study show that it takes 1.4 hours on average to diagnose a hot complaint and 1.7 hours to diagnose a cold complaint. The data also suggest that complaints are not due to differences among individuals, but rather to HVAC faults or poor control performance. Sustainable buildings that have well-designed HVAC and control systems that have been commissioned are less likely to experience these problems.

Another study reports that personal controls for HVAC systems reduce complaints to as low as 10 calls per 1000 employees per year (Loftness et al. 2002). (Those controls can be installed only in conjunction with underfloor air distribution systems.)

Less time dealing with complaints leads to more time to complete preventive maintenance tasks, increasing equipment longevity and lowering operating costs overall.

2.7.3 Decreased Risk, Liability, and Insurance Rates[33]

Building owners and operators face a wide range of risks (described below), which are particularly disruptive and costly in mission-critical governmental activities (civilian or military). Those risks may be partially mitigated by sustainable building design.

- **Property loss prevention.** Various green-building technologies reduce the likelihood of physical damages and losses in facilities (American Insurance Association 1999; Vine et al. 1998 and 1999; and Mills 2003b). For example, sustainable siting reduces the likelihood of property damage from flooding, mudslides, and soil subsidence. Efficient thermal envelopes and reduction in losses from recessed lighting or thermal distribution systems located above ceilings reduce the risk of ice-dam formation on roofs. Using efficient torchiere light fixtures eliminates the fire risk posed by halogen versions.
- **Business interruption loss prevention.** Unplanned power outages and improperly designed or maintained HVAC systems can cause temporary closure of facilities, resulting in disruption of operations and relocation costs (Brady 1995; Eto et al. 2001; and Mills 2001). These business interruption risks can be reduced by using onsite energy generation resources and energy-efficiency features.
- **Hedge against energy price and cost increases.** Energy is a significant part of facility operating costs. The likelihood of budget overruns from unanticipated energy price spikes can be reduced by energy-efficient design that lowers overall consumption.
- **Natural disaster preparedness and recovery.** Various energy-efficient and renewable technologies make facilities less vulnerable to natural disaster events, such as heat catastrophes, which are a particularly high risk for federally operated low-income housing (Deering and

[33] Dr. E. Mills of Lawrence Berkely National Laboratory contributed portions of this section.

Thornton 1998; Mills 2003a). Well-insulated attics, natural ventilation, and heat-reflective roofing materials can considerably reduce indoor temperatures during heat waves, averting hospitalization or loss of life. Using multipane (e.g., triple-glazed) windows can reduce the threat of fire-related losses.

- **Worker health and safety, and risk of lawsuits.** Various benefits result from improved indoor environmental quality, reduced likelihood of moisture damage, and other factors enhancing occupant health and safety (Chen and Vine 1998; Vine et al. 1998). Owners may face lawsuits when their buildings cause illness among occupants. According to a study by the American Medical Association and the U.S. Army, health problems caused by poor indoor air quality cost 150 million workdays and about $15 billion in lost productivity each year in the United States.[34] Increasingly, the issue of sick building syndrome ends up in the courts, with either builders/ designers or building owners being held liable for design flaws or improper operation. For example, in 1995 a jury awarded Polk County, Florida, almost $26 million to correct the contractor's health-related design and construction flaws in the County's eight-year-old courthouse. In 1996 a jury found Dupage County, Illinois, responsible – as the building owner – for health-related complaints at its $53 million courthouse, calling the problems a result of improper O&M.[34]

Risk (and associated losses) has a cost even when organizations are insured. Customer-side costs that occur when insurance is used include deductibles, premiums (and premium increases or policy cancellations due to losses), and possible excess costs if the insurance or reinsurance coverage is capped. If commercial insurance is not used (as is often, but not universally, the case in the government sector), the costs of risk are even higher because the facility owner is either formally or informally self-insured. Formal self-insurance implies that a predefined premium is set aside from internal budgets and accumulated in the form of an earmarked loss reserve. If self-insurance is informal (typically the case in the public sector), then the risks are not explicitly anticipated or otherwise reserved. Where formal or informal self-insurance is used in the public sector, risk management takes on particularly high value because there is no upper limit against loss costs and because losses would usually have to be absorbed in general operating budgets, without guaranty of reimbursement.

When Federal facilities do have insurance coverage, some insurance companies are willing to offer lower insurance premiums for buildings or sites that have incorporated features that not only improve safety but that also have positive environmental effects. For instance, insurance companies have lowered premiums for buildings with high mass walls because they reduce the risk of fire. These walls can also save energy and enhance comfort by storing heat and evening out temperature fluctuations. In another example of lower premiums, the Federal Emergency Management Agency reduced the premium on flood insurance by 5% for all buildings in unincorporated areas of Charleston County, South Carolina, based on voluntary efforts on the part of the developers of Dewees Island to improve the county's flood management capabilities by taking actions to reduce the chance of flooding on the island.[34]

A number of forward-looking insurers have endorsed or otherwise supported energy-efficient and renewable energy technologies by initiating various types of programs or policies (Mills 2003b). In some cases, insurance companies have offered premium credits of about 10% when the insured implemented selected energy-saving strategies. For example, the nation's largest professional liability insurer – DPIC – offers 10% credits for firms that practice commissioning, and the former

[34] Rocky Mountain Institute website: http://www.rmi.org/sitepages/pid221.php.

Hanover Insurance Company offered 10% credits for earth-sheltered or solar buildings on the basis that lower fuel-based heating system operating hours reduce fire risk (Mills 2003b).

2.7.4 Greater Building Longevity

> *"If our buildings are not designed to last at least 250 to 300 years, we're not asking the right questions."*
>
> John Abrams, South Mountain Company (quoted in Building Green Inc. 2003)

Many of the principles of sustainable design lead to longer building lifetimes and better adaptability of the building for future uses that cannot always be foreseen. If buildings do not have to be frequently demolished and replaced, total construction costs will be lower over the long run. For instance, keeping a building's initial form simple will make it easier to change as needs evolve. Using open-web joists and modular access flooring systems makes refitting buildings for new uses less complicated. Designing rooms as multipurpose spaces allows them to be adapted for future changes in use (e.g., from residential to commercial space). Other strategies for adaptability include selecting durable materials that age well; designing roofs to be photovoltaic-ready; designing the building foundation and structure to accept additional floors at a later date; avoiding partitions and leaving as much open space as possible; and designing with classic and regionally appropriate styles.[35]

2.7.5 Better Resale Value

Although turnover of Federal government buildings is not as frequent as in the commercial real estate market, the Federal government does sometimes sell unneeded facilities. For instance, in 1998, the GSA sold over 1,500 properties for a total of about $250 million. In subsequent years, the GSA has sold between 130 and 300 buildings per year, for a total price per year of $312 million to $479 million.[36]

Research shows that investing in sustainable design features, such as energy- and water-efficiency measures, can considerably increase the resale value of a property because it lowers annual costs and therefore makes a building more profitable for the new owner (Chou and Parker 2000). Real estate investors evaluate building values based on cash flow and net operating income (NOI), which is the pretax operating income minus operating expenses, excluding debt service. Reducing utility costs increases NOI. A case study showed that a one-time investment in energy- and water-efficiency upgrades that cost $0.95/ft^2$ (1.8% of the purchase price) saved $0.66/ft^2$ in annual operating costs (equal to 15% of NOI) (Mills 2002). These savings increased the estimated resale value of the property (a small apartment building) by $36,000 to $46,000 (for prevailing capitalization rates of 9% and 7%, respectively) – about ten times the initial investment for the improvements.[37]

2.7.6 Ease of Siting

The inherent environmental benefits of a sustainable building will reduce its adverse environmental impacts and enhance its acceptability to regulatory bodies, the surrounding communities, environmental groups, and other interested parties. These benefits will tend to lower both the time delays and the cost associated with siting the building, including obtaining permits and performing

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[35] Many strategies for making buildings adaptable for new uses are outlined in a recent article in Building Green Inc. (2003).
[36] Personal communication from R. Rice, GSA.
[37] The capitalization or CAP rate (also knows as return on assets, ROA) is defined as the ratio of NOI to the property value. The ratio NOI/CAP provides an approximation of property value.

environmental impact studies. Gaining early respect and support from a community can greatly speed up project approvals. For example, the developers of Central Market, a grocery store in the town of Poulsbo, Washington, say that the decision to enhance an onsite wetland and offer it to the city as a park not only reduced maintenance costs but also avoided delays by generating strong community support. The developer, Sam Clarke, Executive Partner of the Hattaland Partnership, stated, "The city of Poulsbo and key community leaders are well aware of our work [to enhance the environment] —this establishes trust and respect, which translate eventually into financial advantages."[38]

2.7.7 Strategic and Economic Value of an Improved Image

An organization that owns and operates a sustainable building will tend to capture intangible value through stakeholder awareness and respect. While difficult to quantify precisely, this effect undoubtedly creates strategic advantage in dealing with various stakeholders, e.g., nongovernmental organizations, other agencies, and the public. In essence, the sustainable nature of the building can be considered a symbolic message to building visitors, as well as community members and passers-by who recognize its distinctive character. For example, innovative sustainable buildings in the private sector, including the headquarters buildings of The Gap and Herman Miller, as well as the Ford Motor Company Rouge Plant, have received extensive positive media coverage.

Key aspects of the message conveyed by a sustainable or green building include technological advancement, architectural innovation, and concern for humanity and the environment. The building owners can promote this message through various awareness-building techniques, including posters, brochures, organized tours, and media publicity. When the sustainability of the building reinforces the primary mission of a Federal agency (e.g., environmental management, energy efficiency, and technological innovation), this "image value" will be particularly powerful. Community groups, elected representatives, nongovernmental organizations, and others involved in the political process may view the Federal agency owner of a sustainable building as a supporter of their interests, and this positive view can translate into improved political support.

Some research has been conducted to evaluate indirect financial benefits of corporate sustainability efforts. While these efforts have not been directed specifically at sustainable building projects, they do have some relevance to understanding the value of the improved image associated with an organization's sustainability-related activities. For example, a number of "environmental accounting" techniques have been developed, using economic value added and other shareholder value measures, to estimate the likely future cash flows related to the environmental impacts of capital investments and facility siting decisions (Epstein and Young 1999).

One ongoing project by SustainAbility, a strategic management consultancy and think tank based in Europe, has established a mapping between business value measures and dimensions of corporate sustainable development performance, with documented examples that will be expanded through continued updating (SustainAbility and United Nations Environmental Program 2001). The SustainAbility project found strong evidence linking access to capital and shareholder value to a company's commitment to environmental process improvement. They also found strong evidence linking corporate revenue to good workplace conditions. These results indicate that both environmental and social aspects of sustainable design may impact a company's economic performance. Although the government is not motivated by revenue and shareholder value per se,

[38] Excerpted from Rocky Mountain Institute website: http://www.rmi.org/sitepages/pid221.php.

some government analogs to these metrics exist (e.g., revenue and access to capital in the private sector could be viewed as analogous to higher budget allocations in a government setting).

In another effort, the American Institute for Chemical Engineers (1999) developed a total cost assessment methodology for managerial decision-making that identifies the full range of environmental- and health-related costs associated with the lifecycle of a business decision, including indirect, contingent, and intangible costs. The World Resources Institute recently published a critical survey of the available methods for quantifying the business case for sustainability (Reed 2001). The greatest impediment to applying these types of quantitative methods is the absence of sufficient empirical data. Not enough experience exists yet with sustainable business decision-making to satisfy the needs of financial analysts. However, as this section has discussed in detail, research has been conducted on many important economic benefits of sustainable buildings, from which good inferences can be drawn about the strategic and financial advantages of sustainable design and construction.

2.8 Indirect Economic Benefits to Society

Building construction, operation, and demolition have a variety of environmental impacts, including air pollution emissions, greenhouse gas emissions associated with climate change, solid waste generation, water pollution, natural resource depletion, and habitat disturbance (see Section 4). Sustainable design aims to significantly reduce these impacts. These improvements will reduce the health effects and costs associated with environmental pollution and will have other less tangible economic value to society. In addition, by reducing energy consumption and waste generation, widespread application of sustainable design principles to new construction and renovations will, over time, reduce the need for new infrastructure required to support buildings – e.g., power plants, transmission and distribution lines, and landfills – and may foster local and regional growth in emerging businesses related to sustainable design. The economic aspects of these societal benefits – decreases in environmental pollution, reduced infrastructure needs, and local/regional business growth – are discussed in the sections below.

2.8.1 The Value to Society of Environmental Preservation and Pollution Reduction

Sustainable design strives to lower energy consumption and the resulting air pollution and greenhouse gas emissions, as well as to preserve natural resources, wildlife habitats (e.g., forests and wetlands), water bodies, scenic vistas, and other environmental assets. Economic values placed on such environmental "goods" are currently used for various purposes (mostly legal and policy issues), and natural resource economists have developed various means to estimate the value of natural resources and environmental impacts. Although some would say that something like a unique ecosystem is "priceless," certain groups within American society place economic value on, and are willing to pay for, environmental and natural resources. For instance, the Nature Conservancy is planning to invest $1 billion to save 200 of what they call the world's "Last Great Places."[39]

Various approaches have been applied to place a dollar value on reductions in air pollution emissions. One way is to examine the price firms pay to buy pollution "credits." The Clean Air Act established a program by which power plants were required to reduce their emissions of sulfur dioxide (SO_2) to a specific emission cap. The program allowed companies that could reduce emissions below their caps to sell the extra reductions ("credits") to other firms, allowing those other

[39] http://nature.org/aboutus/campaign/.

firms to emit above their caps. As time progressed, firms with high costs of SO_2 control have chosen to buy credits from those with lower costs of control.

These emission credits are openly traded in the market. Recent prices have ranged from \$90 to \$272 per ton (National Research Council 2001). In addition, New Jersey and five other states in ozone nonattainment zones[40] have developed open market emission trading programs whereby building owners can generate emission credits by investing in energy efficiency, measuring the electricity saved and determining (based on a prescribed formula) the amount of air pollution emissions that were avoided by not generating the electricity. These credits have been sold for about \$1000 per ton for nitrogen oxide (NO_x) (New York City Department of Design and Construction 2000). However, the current market value of air pollution credits does not necessarily reflect the full cost of pollution damages, e.g., negative health and welfare impacts.

A number of research studies, using a variety of methods,[41] have estimated the societal cost of a pollution. The cost ranges are wide because the methods and assumptions are diverse. The studies estimate the costs as follows (National Research Council 2001):

- Emissions of SO_2 at \$100 to \$7500 per metric ton (\$91 to \$6800 per ton)
- Emissions of NO_x at \$2300 to \$11,000 per metric ton (\$2090 to \$10,000 per ton)
- Emissions of carbon dioxide (CO_2) at \$6 to \$11 per metric ton (\$5.50 to \$10 per ton).

These values could be used, especially within a Federal government context, to estimate the societal benefit that reduced energy consumption in sustainable buildings has on reducing emissions.

In the prototype building analysis described in previous sections, the energy-efficiency measures led to the following emission reduction estimates: 0.16 tons of SO_2, 0.08 tons of NO_x, and 10.7 tons of CO_2.[42] Using the maximum values in the ranges above, these emission reductions might be valued as high as \$1090 (for SO_2), \$800 (for NO_x), and \$107 (for CO_2), with a total annual cost reduction to society of \$2000. This value (\$2000) could be used to represent the annual benefit to society that would partially offset the incremental first cost of the energy-efficiency measures (which, in this case, was \$38,000). Including these societal cost reductions in the payback calculation lowers the payback period from 8.7 to 6.0 years.

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[40] Nonattainment zones area areas with ambient concentrations of air pollutants that exceed the standards set to protect health and welfare.

[41] Some of these methods include indirect observed behaviors, direct hypothetical behavior, and indirect hypothetical behavior (for an overview, see descriptions by Randall [1987]; Freeman [1992]). The indirect observed behavior method tries to relate the value of a nonmarketed good (such as the price people would pay for a clean environment) to a marketed good (such as the price people would pay for recreational fishing). Economists commonly use the travel cost method or the hedonic/implicit price method. The travel cost method uses travel expenditure as the price paid to access a site, such as a natural park, to estimate a demand for that site. The hedonic/implicit price method investigates how a nonmarket good influences the value of a market good; hypothetically, this method could be used to estimate how a pristine environment surrounding a building might influence the rent or market price for that real estate. Direct and indirect hypothetical behavior uses hypothetical questions to elicit the value of a nonmarket good from a respondent (contingent valuation method).

[42] Expressed in tons of carbon in CO_2.

2.8.2 Reduction in Municipal Infrastructure Requirements

Taxpayers and local/regional governments benefit financially when they are required to invest in fewer new infrastructure projects. Some ways infrastructure needs are reduced through sustainable design include the following:

- Siting buildings near public transportation and including other features that encourage public and bicycle transportation rather than use of personal vehicles not only can reduce air pollution but also can reduce regional road and highway infrastructure requirements.
- Redeveloping brownfield sites or locating new buildings in downtown areas rather than suburban or rural greenfield sites reduces the associated development costs for new transmission/distribution systems, sewer systems, roads, and other infrastructure systems.
- Using recycled materials and construction waste management reduces demand for landfill capacity and therefore landfill construction costs.
- Reducing water use lowers the need for new wastewater/sewage treatment plants.

2.8.3 Local and Regional Economic Growth

Long-term socioeconomic benefits to a community and region may be realized if enough builders and building owners adopt sustainable design practices. For example, the sustainable buildings industry could foster a market for recycled materials and energy-efficient systems, creating sufficient economies of scale to reduce the price of these types of products to be more competitive with conventional products. In addition, surrounding communities and the region may experience economic development through emergence of businesses that make sustainable materials; produce energy-efficient technologies; and provide sustainable design, construction, and commissioning services. A region prone to practicing sustainable design and construction is an attractive place for these companies to locate. This potentially produces additional local jobs and income. Government sustainable design projects can be a "seed" for growth of sustainable communities and regions.

Sustainable building design also tends to favor local sources of materials and labor, further stimulating the economy adjacent to the building site and providing economic benefits that are particularly important in areas that are economically disadvantaged. For instance, the State of Oregon recently passed legislation, and the Governor signed an Executive Order, to promote sustainability in various government functions. One aspect of the initiative involves improving contracting practices to ensure that local contractors and businesses have competitive opportunities in rural and distressed communities.[43]

> *"Building on the many laudatory accomplishments of past generations, I want my generation, and my administration, to ensure that following generations can flourish and leave to their children a healthy and stable Oregon. We can and must reduce the pressures on our environment while increasing economic growth and community health."*
>
> Oregon Governor Ted Kulongoski, "Rally for the Environment Remarks," March 24, 2003. See http://www.oregonsolutions.net/oregon/index.cfm.

Another potential impact of sustainable design is an increase in property values adjacent to the sustainable building site. The characteristics cited above that contribute to quality of life will also tend to enhance the desirability of the neighborhood for developing other economic enterprises, including residential housing.

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[43] http://www.oregonsolutions.net/govt/group.cfm.